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Development and Evaluation of a Charcoal-Insulated Paddy Storage Bin

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ABSTRACT: *A charcoal-insulated storage bin for grains was designed and evaluated. The headspace temperature and humidity were observed for four months. Paddy temperature and moisture content were monitored at 8:00am, 12:00 noon, 4:00 pm and 8:00 pm from three observation points located at the bottom, middle and top sections of the stored rice. For comparison purposes properties of stored rice in hermetic bags, (woven plastic) polybags and insulated bin, each containing 500 kg were monitored during four months of storage. Headspace temperature did not change in four months while humidity increased after three months. The insulated bin was able to reduce temperature fluctuation on different locations of the bin at different times of the day. Paddy temperature and moisture content were maintained at safe storage level. Moisture migration and hot spots were not detected. No sign of rotting was reported. Insect presence were greatly reduced. There were no losses due to rodents and birds. Seed viability in the bin was lowest among the storage systems compared in this study. Milling quality was best due to least amount of cracked grains.*

Keywords: *charcoal, insulated silo, paddy, silo, rice hull*

I. INTRODUCTION

A charcoal-insulated bin was designed and fabricated to provide storage for small- and medium-scale farmers. A storage facility for smallholder farmers is necessary since most modern and sophisticated facilities are neither applicable nor affordable to them.

Storing seeds and grains continues to present challenges to crop production. Most farmers store grains in sacks and pile them up in a warehouse or somewhere within their dwelling place. This technique, however attracts mice and birds so that losses are high, prompting farmers to sell their produce as soon as possible, only to buy them back later for seed purposes or family consumption at a higher price.

In the 1980s, a flat-type metal silo technology was developed in Honduras with technical and financial support from Swiss Cooperation in Central America SDC. The Food and Agriculture Organization (FAO) subsequently disseminated this technology in 16 countries [1]. These silos provide a physical barrier against insects, birds and rodents. They are airtight, easy to use and inexpensive and require little space. Capacity ranges from 100 – 3000 kg [2]. They have been found to improve food security, empower smallholder farmers, enhance income opportunities and safeguard ecosystems [3].

In China, metal silos were designed to provide protection against seasonal fluctuations in grain prices. Intended for small- and medium-scale farmers, these silos are cylindrical with airtight-seal, wheels on metal-frame and truncated top and bottom [4].

Metal silos are not without problems in warm and humid condition. Metals heat up the air inside the silos when outside temperature is high. As temperature falls to dew point, condensation occurs. Condensate rewets grains and initiates mold formation, and eventually spoilage.

Several techniques have been employed to prevent condensation inside the metal silos. For this purpose, a wooden silo was designed and tested. A prototype was made of double-layered panel of plywood with a small air gap in between for heat insulation. Condensation was successfully eliminated but delaminating and peeling of sheathing materials were detected [5].

Another solution to moisture condensation was to use termite mound clay for grain silo construction [6]. Temperatures were measured inside and outside the silo, and the quality of grain stored in the silo was monitored over a period of two months. Inside the silo temperature fluctuations amounted to 9.5°C while fluctuations of air temperature outside the silo reached 10.3°C. Seed viability was decreased from 88% to 84% in two months of storage.

Another researcher [7] designed a double-walled metal silo with a capacity of 350 kg. Walls were 5 cm apart to accommodate wood shavings, which were intended to act as insulators. Temperature fluctuations inside the silo were lower than those outside the silo. Moreover, temperature differences on different depths of stored maize differed significantly. The silo showed some promising prospects in grain storage.

Although there have been numerous studies describing changes during rice storage, only Adejumo [7] to our knowledge focused on insulated rice bin to maintain constant temperature and relative humidity. Most studies typically limited their focus in using aeration to reduce the temperature and relative humidity inside. With the promising scenario of double-walled insulated silo, this study focused on the design and testing of carbonized rice hull-insulated bin for rough rice. The study was designed to monitor the headspace temperature and humidity as well as the rough rice condition from different depths of storage for four months. (10). For comparison purposes, rough rice was stored in hermetic bags (IRRI superbags) and woven plastic (polybags) and insulated bin. Each storage system contained 500 kg rough rice. Rice quality was determined after four months.

II. MATERIALS AND METHODS

Rough rice variety RC 222 from a single harvest was procured from a local farmer to ensure uniform paddy characteristics.

The storage bin was designed as a sealed container with insulation to avoid interactions with the environment, thus preventing changes in grain moisture content. Charcoal or carbonized rice hull was used as insulating material. The insulation was sandwiched between an inner wall of stainless steel and an outside wall of GI sheet. Stainless steel was used to prevent corrosion; GI sheet was used to prevent attacks from birds, rodents and insects. Paddy was stored at moisture content of 12.36% (dry basis). Outside temperature at the time of loading was 27°C and relative humidity was 90%.

2.1 Design and Fabrication

The storage bin was designed to hold 500 kg of rough rice. A rectangular bin with inside dimensions of 0.85 m x 0.85 m x 1.03 m was found adequate for this amount of paddy.
The thickness of the insulating material was determined from:

$$Q = \frac{A\Delta T}{\frac{x_1}{K_1}+\frac{x_2}{K_2}+\frac{x_3}{K_3}}$$

where Q is the heat load from paddy, A is the surface area of the wall, ΔT is the difference in temperature outside and inside the bin, x is the thickness of the wall material and K is the thermal conductivity of the material.

Based on paddy load of 500 kg with latent heat of 645 kcal-kg-1, the thermal conductivities of 0.062 W/m°K, 80 W/m°K, and 16 W/m°K for carbonized rice hull (charcoal), GI sheet and stainless steel, respectively, and temperature difference of 90K, the charcoal thickness was found to be 2.5 cm. Square tubes were used to support the metal walls.

A conical bottom leading to the discharge chute was provided for ease of discharge. The bin is mounted on a sturdy frame for support. The vertical clearance of the discharge chute from the ground floor was designed to discharge paddy by gravity to an empty sack.

2.2 Testing and Evaluation

The performance of the bin was determined from the data gathered on the storage headspace and stored rough rice. Observations were conducted three days every month from November to February 2016. Samples were taken from observation ports at 8:00 am, 12:00 noon, 4:00 pm and 8:00 pm. Observation ports were located at different depths of the bin: bottom, middle and top.

A digital temperature-relative humidity meter was used to determine the temperature and relative humidity of the air space of the bin.

For comparison purposes, 500 kg of paddy was stored in hermetic bags and another 500 kg in poly bags (woven plastic bag) at the same time that 500 kg of paddy was stored in the insulated bin. Paddy for all treatments were from the same seed lot to ensure the same variety, production, harvesting and drying treatments. All tests were conducted in triplicate.

Stored rough rice properties were determined using 100-g paddy sample for moisture content determination.

A 50-g sample was used to determine the number of grains, clean paddy and dockage. The number of insects present per kilogram were determined using magnifying glass.

A sample of 100 grains was used to determine seed germination rate using ragdoll method. Germination was reported five days after sowing. Seed vigor index (SVI) was determined from the product of the total length from the shoot to the roots and the germination rate.

Germination speed was determined from the number of seedlings that emerged daily from day one of planting until the time germination was complete. The equation used was:

$$germination\ speed = \frac{n}{d}$$

where n = number of seedlings emerging on day “d”
d = day after planting.

III. RESULTS AND DISCUSSION

This study aimed to design and fabricate an airtight charcoal-insulated silo for rough rice storage. Its performance was based on rice quality after storage compared with those stored in hermetic bags and polybags.

3.1 Specifications of the Storage Bin

The storage bin consists of a rectangular chamber with a flap door on top, a rubber seal at the door, a conical discharge chute beneath the chamber, a sliding door at the bottom of the chute and a frame to support all the parts.

The bin has a capacity of 500 kg with an overall height of 2,710 mm. The chamber measures 920 x 930 x 1120 mm. Double walling was used to prevent temperature migration from the environment to the paddy inside the chamber.

Walls are made of GI sheet and stainless steel with rice hull charcoal sandwiched in between. Square tubes are used for added strength and join the sheets together. The roof is a flap door with rubber along the edges to seal the grains inside and prevent entry of air into the chamber.

A conical outlet chute with sliding door is used for discharge of content. The chute is provided for ease of releasing the grains by gravity when needed. The sliding door of the outlet chute is 1108 mm above the ground to allow ample space for the full height of a standing sack during discharge.

A sturdy frame made of angle bars supports the structure. Charcoal is used as insulator. Rice hull was carbonized for this purpose. Based on computation a 25-mm gap between walls was filled with charcoal.

Three observation ports are provided on one side of the bin. These ports allow collection of samples from the bottom, middle and top portions of the bin. The ports are 10 mm in diameter and are properly sealed when not in use.

Loading of paddy presented some difficulties due to the height of the opening. A 2-man team was necessary for loading – one on a ladder propped against the bin and another to hoist the paddy using a pulley.

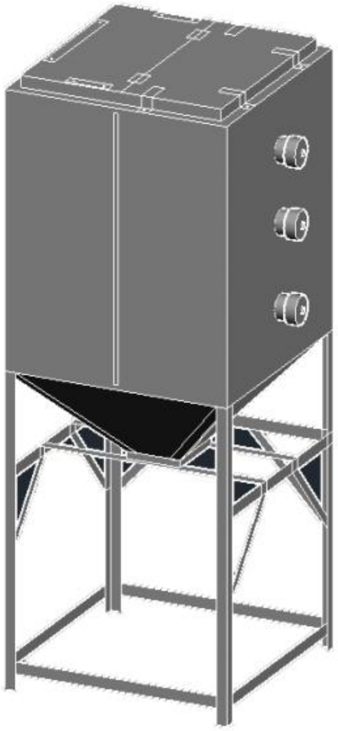

Figure 1. Isometric view of the charcoal-insulated storage bin

3. 2. Headspace and Paddy Condition inside the Insulated Bin

The average temperature at the headspace of the bin did not change during storage while the relative humidity dropped on the 4th month of storage. A similar study monitored the temperature and relative humidity of air inside metal and wooden silos for 130 days (roughly 4 months and 10 days). The average temperatures were 29.95°C for metal silo and 29.25°C for wooden (plywood) silo. The average relative humidity based on lowest and highest records inside the silo were 72.5% for metal and 80.7% for wooden [8]. The difference was attributed to lower heat conductivity of wood compared to metal.

Headspace temperature and humidity play an important role in storage as they affect the biological, physical and chemical activities of organisms on the surface of stored paddy. Convective heat transfer from outside air causes headspace temperature variation which mayfavor condensation of moisture on the silo walls. However, condensation will occur only if the temperature drops below dew point – below 25°C in this case. Since the temperatures hardly changed during the storage period, condensation was unlikely. Moreover, the bin was sealed to prevent the entry of moist air from outside.

Table 1. Storage condition in the head space of the insulated bin and paddy moisture content during four months of storage.

Month	Temperature, °C	Relative Humidity, %
December	28.93	80.44^{a}
January	28.26	77.44^{a}
February	28.04	70.89^{b}
P-value	0.6507	0.0846
CV (%)	5.9441	9.2075

Means not sharing letter in common differ significantly at α = 0.05 by Fischer's Pairwise Comparison.

3.3. Paddy Condition inside the Bin

The temperatures of paddy changed within the day (Table 2) – indicating the effect of time on seed temperature. Temperatures were low at 8:00 in the morning and 8:00 in the evening and high at 12:00 noon and 4:00 pm. No temperature differences were noted between 8:00 in the morning and 8:00 in the evening as well as between 12:00 noon and 4:00 pm. Highest temperature difference inside the bin was 0.29C°; 3.36 C° outside the bin. The temperature at the top section of the paddy was the same as that of the ambient temperature. The bottom and middle sections of the paddy shared the same temperature which are higher than the temperature at the upper section. Highest temperatures were recorded on the top section.

A study carried out to determine the temperature inside a double-walled metal silo with sawdust as insulating material found that the temperatures inside the silo were significantly lower than those outside. Temperature was observed to increase from the bottom to the upper part of the silo [9]. Highest temperature on top portion of the silos contrary to the result of this present study. An important indicator of trouble in storage is temperature. Any rapid change could mean hot spots indicating mold formation, spoilage or insect growth. As a rule of thumb, when paddy reading is 27°C-30°C, a rise of 6 degrees is a warning [10]. This insulated bin maintained a stable paddy temperature for four months.

Table 2. Diurnal temperature variation inside and outside the bin at different bin locations

Location	8:00 AM	12:00 PM	4:00 PM	8pm	Mean
Bottom	29.03	29.49	29.27	29.20	**29.222**^{a}
Middle	28.98	29.41	29.29	29.40	**29.203**^{a}
Top	28.67	28.77	28.80	29.50	**28.789**^{b}
Outside	27.89	29.56	29.51	26.20	**28.417**^{b}
Mean	**28.586**^{b}	**29.306**^{a}	**29.217**^{a}	**28.522**^{b}	

Means not sharing letter in common differ significantly at α = 0.05 by Fischer's Pairwise Comparison.

Monthly paddy temperatures and moisture contents during storage are shown in Table 3. It may be noted that the monthly temperatures did not change during storage ($p = 0.304$ at $\alpha = 0.05$). In a similar study, a rice silo made of termite mound clay was designed and fabricated [6]. Storage was monitored for 60 days by comparing the temperatures inside and outside the silo. This study recorded a temperature difference of 10° within the silo in 24 hours. It was slightly more stable than the temperature fluctuation outside the silo. In comparison, temperature fluctuation inside the insulated bin of this present study is much lower than fluctuation inside the termite mound clay silo. In another study on paddy temperatures stored in a metal silo for six months, the readings dropped drastically starting on the fourth month.

This was attributed on the drop of ambient temperature, indicating the effect of the environment on stored paddy [11]. In contrast to this report, the insulated bin storage maintained the temperature until the fourth month. Moisture content of paddy in the insulated bin showed a significant increase on the second month. This value was subsequently maintained until the 4th month. The fluctuation between the initial and the 4th month was an increase of 0.266 percentage point from the initial value. The moisture content of paddy in this insulated bin is comparable with the moisture level of paddy stored in in hermetically sealed bags (IRRI-super bags) for four months. This implies the potential of the insulated bin to be used as an alternative to hermitic bag storage [12].

Table 3. Monthly paddy temperature and moisture content during storage at the insulated bin

Month	**Temperature. °C**	**Moisture Content, %**
November	29.000	12.3667^{b}
December	29.064	12.567^{a}
January	28.900	12.567^{a}
February	29.250	12.633^{a}
P-value	0.304	0.4461

Means not sharing letter in common differ significantly at $\alpha = 0.05$ by Fischer's Pairwise Comparison.

3.3. Stored Paddy Characteristics in Different Storage Systems on the 4th Month of Storage

Paddy temperatures did not differ across all storage systems (Table 4). Moisture content was highest in the insulated bin, lowest in poly bags but remained within safe level of storage. High moisture content in the bin may be attributed to higher temperature due to paddy respiration. On the 4th month of storage, temperatures of different storage systems were still the same.

Moisture content was maintained at safe level of < 14%. Grain moisture is the most significant property because of its effect on the multiplication of insect pests. Moisture is also a major factor affecting seed deterioration, which increases as moisture increases. Apparently, paddy was sealed from outside air which could have induced moisture absorption. This implies the potential of the insulated bin to be used as an alternative to hermitic bag and poly bag storage. Insect density was 20 per kilogram in the insulted bin, 20 in the hermetic bags and 114 in poly bags. In the bin, most of the insects were dead; more insects were found on the top portion of the paddy. There were no signs of bird droppings or rodent feces within the storage area of the insulated bin and hermetic bags. This indicated no losses incurred during storage. The same zero losses on metallic bins was also reported by Tran [13]. No differences were found in the germination rate of seeds from different storage systems. Seed germination was 82.67% in the insulated bin. Other researchers [11] report a much lower germination rate of 74% on the 4th month of storage in a metal silo of GI sheet, and designed with a capacity of 5 ton.

The tests on the ability of the systems to store paddy for seed purposes showed that germination rates were not affected by the storage system. Germination rates in all cases were greater than 80%, the minimum Standard for both Foundation Class and Certified Class [14]. However, the hermetic bag stored paddy with highest seed quality based on seed vigor index and speed of germination after four months. Seed vigor index is a means of comparing the physiological potential among seed lots and this represents a more sensitive parameter than the germination test. On the other hand, rapid germination indicates more rapid seedling emergence in the field.

Insect presence and losses were extremely high on poly bag storage. This implies greater ability of the insulated bin to protect paddy from insects, less chances of deterioration and hence better quality and selling price. On milling quality, mean values for percent whole, broken and damaged showed no differences across all treatments. Cracked grains were least for samples from insulated bin, followed by samples from hermetic bags and then samples from poly bags. In the insulated bin 76.33% was whole; 2% was broken; 5.33% was cracked. These results conform with IRRI (2009) that the potential (laboratory) milling recovery is 68-72% depending on rice variety [15,]. In a similar study on stored paddy in a metal silo, 73.58% was whole on the 4th month while 31.6% was broken [11]. Cracked grains result from exposure to fluctuating temperature and moisture content. Cracks in the kernel will result to rice breakage during milling. Hence, cracked grains indicate the potential of the seed lot to reduce the amount of whole grains, and the quality and selling price.

Table 4. Properties of rough rice on the fourth month of storage in different systems

Seed Properties	**Insulated Bin**	**Hermetic bag**	**Poly Bag**
Temperature, °C	29.25	28.40	28.30
Moisture content, %	12.63^{a}	12.10^{b}	12.30^{ab}
Insect presence, pcs/kg	27	20	114
Storage loss, kg	0	0	1.44
Seed Germination rate, %	82.67	89.00	87.33
Seed Vigor index	17.24^{b}	29.32^{a}	25.17^{ab}
Germination speed, plants per day	23.97^{b}	28.71^{a}	24.66^{b}
% whole	76.33	68.67	69.00
% Broken	2.00	3.00	2.67
% Cracked	5.33^{b}	7.00^{ab}	$9.^{33a}$
% Damaged	16.33	21.67	19.00

IV. CONCLUSION

An airtight charcoal-insulated bin was designed and fabricated to hold 500 kg of paddy for small- and medium-scale farmers. There was difficulty in loading the bin due to its height, but unloading was convenient.

The insulated bin successfully kept the headspace temperature stable for four months while relative humidity increased on the fourth month.

The temperature fluctuation on different locations of the bin was greatly reduced. Temperature did not change during the day, and was lowest near the top. Paddy temperature and moisture content were maintained at safe storage level. Moisture migration and hot spots were not detected. No sign of rotting was reported.

Insect presence were greatly reduced. There were no losses due to rodents and birds. Seed viability in the bin was lowest among the storage systems compared in this study. No differences in milling quality were detected except for cracked grains which were least in bin storage.

Paddy could be stored for seed and food consumption purposes for at least four months. Distribution of bins to some farmers and traders may be pursued to test its acceptability.

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